

MAPS Technical Overview

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MAPS Performance Specifications

- **Inner Silicon tracking driven by heavy flavor jet performance**
- Track acceptance: $-1.1 < \eta < +1.1$ and $0 < \phi < 2\pi$
- Minimum vertex acceptance: $-10 \text{ cm} < z_{\text{vtx}} < +10 \text{ cm}$
- Meet or Exceed a 30% b-jet efficiency at 30% b-jet purity
 - defined by the CMS of b-jet figure-of-merit
- Minimum track efficiency: $>95\%$ of all charged particles
- Minimum DCA_{XY} resolution: < 70 microns
- Resolve multiple collisions vertexes at large collider luminosities
- Maintain track momentum resolution:
 - Upsilon mass: $dp/p < 1.2\%$ for $4 < p_T < 10 \text{ GeV}/c$
 - Jet Fragmentation: $dp/p < (0.2\% \times p)$ for $p_T < 40 \text{ GeV}/c$
- Maintain small rate of tracking ambiguities: *fake tracks*

sPHENIX MAPS Description

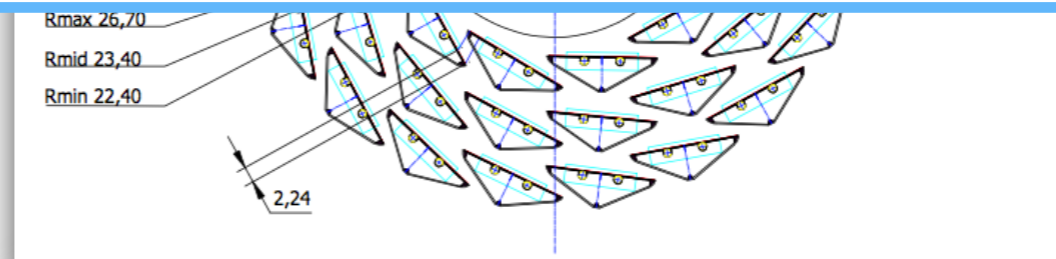
- ALICE ITS Inner Barrel Staves

Why select MAPS?

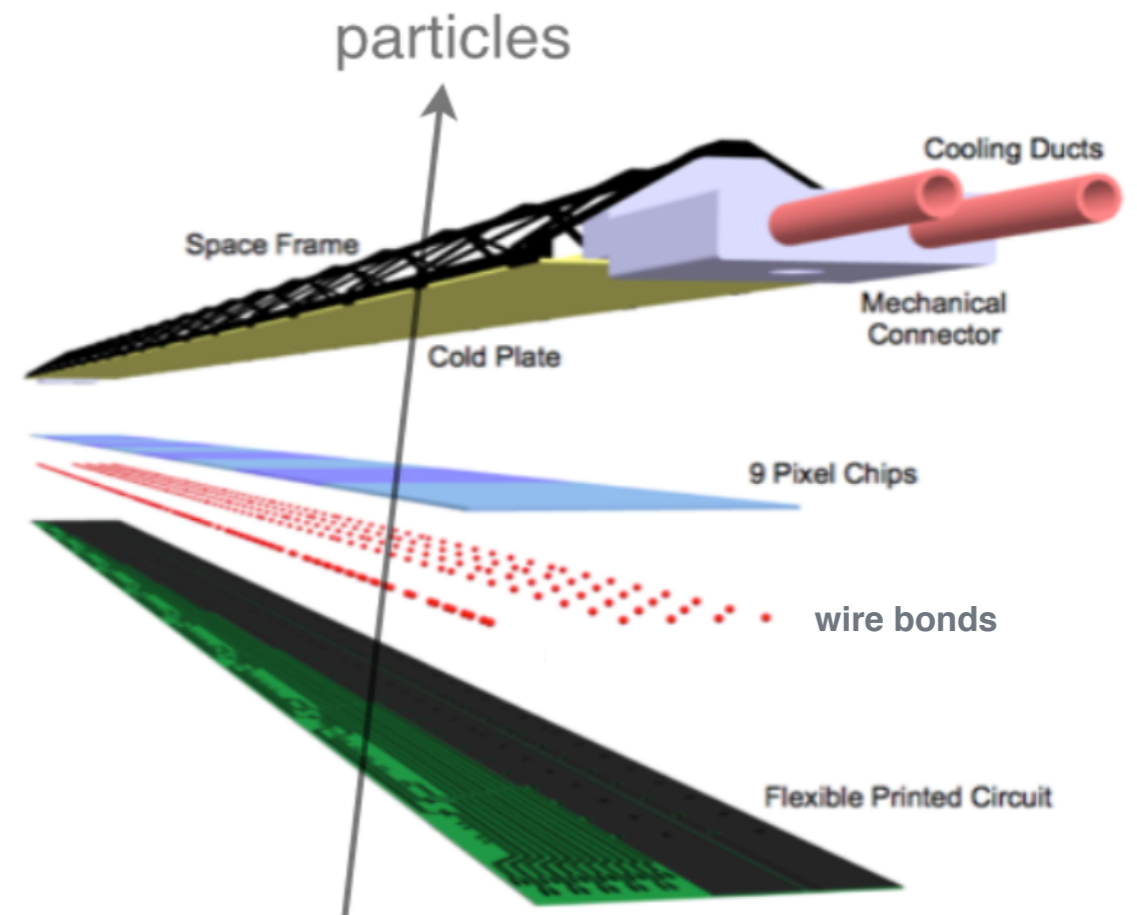
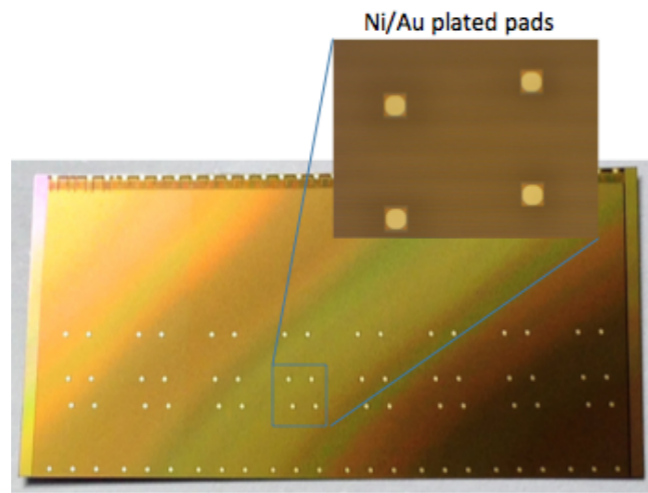
Minimize Risk, Maximize Physics

- Design: ITS IB exceeds our requirements, additional precision
- Savings: 15+ years of ALICE R&D
- Timeliness: Extend the CERN production (2017 & 2018)
- Leverage: US institutions interested in EIC MAPS R&D

- sPHENIX Readout
 - Modified FEM-based on ALICE Readout Unit



sPHENIX MAPS Geometry I

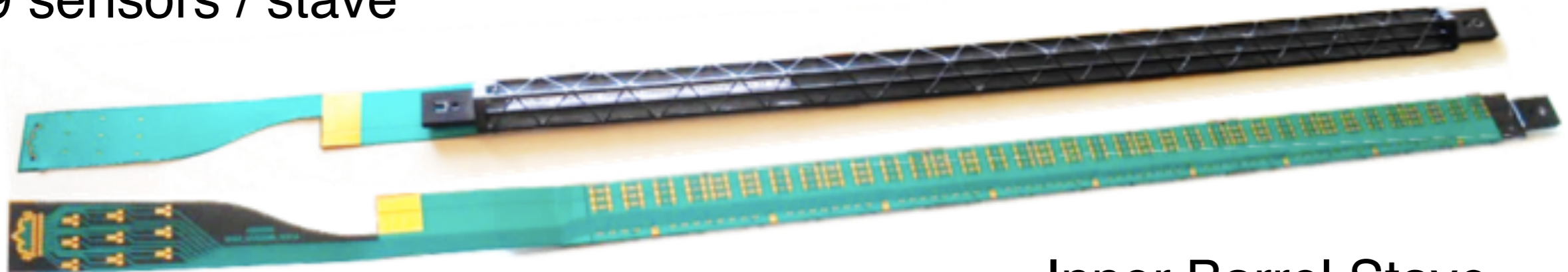


ALPIDE Generation-4 Sensor

1.5 cm x 3.0 cm x 50 μ m

$1024 \times 512 = 0.5\text{M}$ channels / sensor

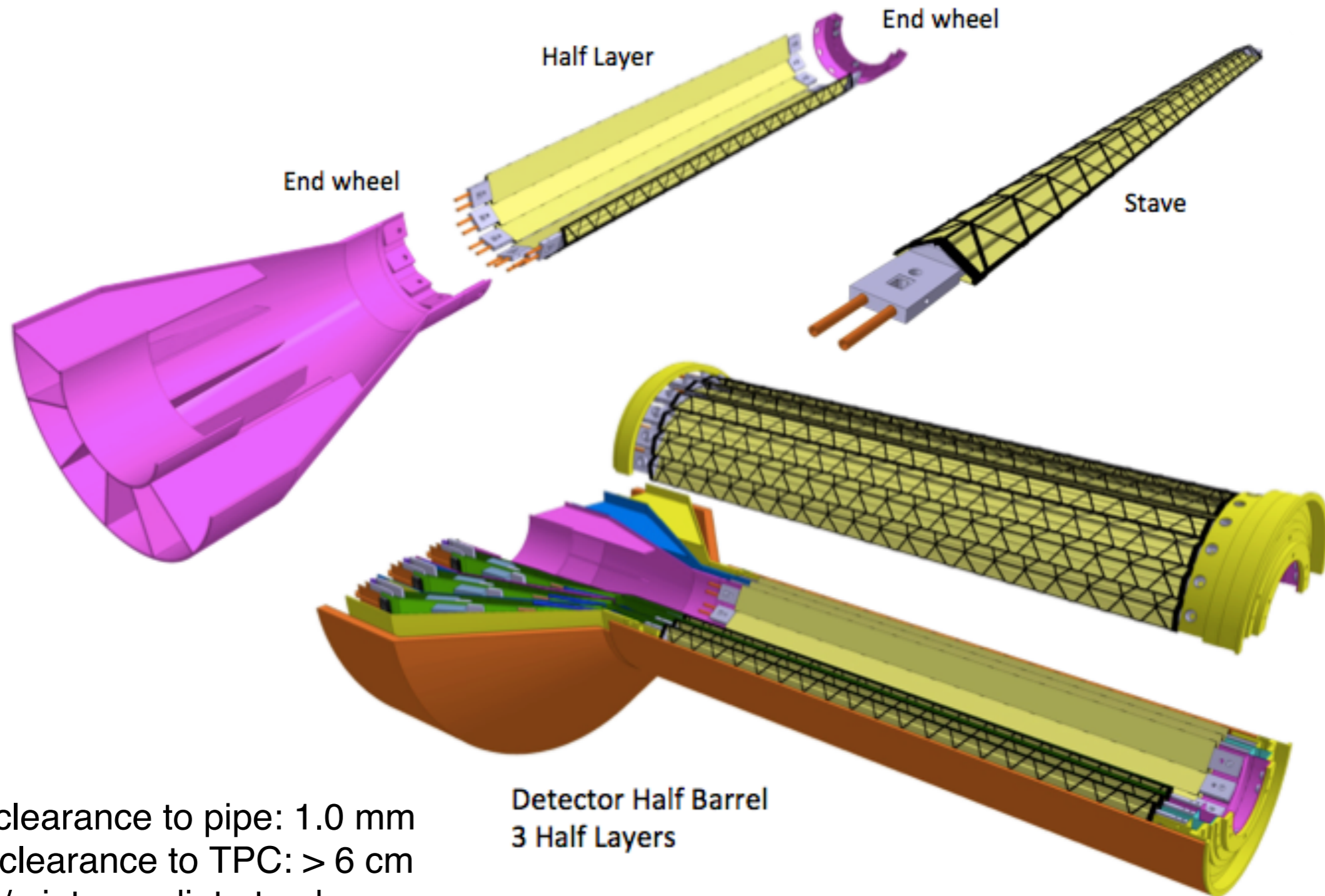
9 sensors / stave



Inner Barrel Stave

1.5 cm x 27 cm

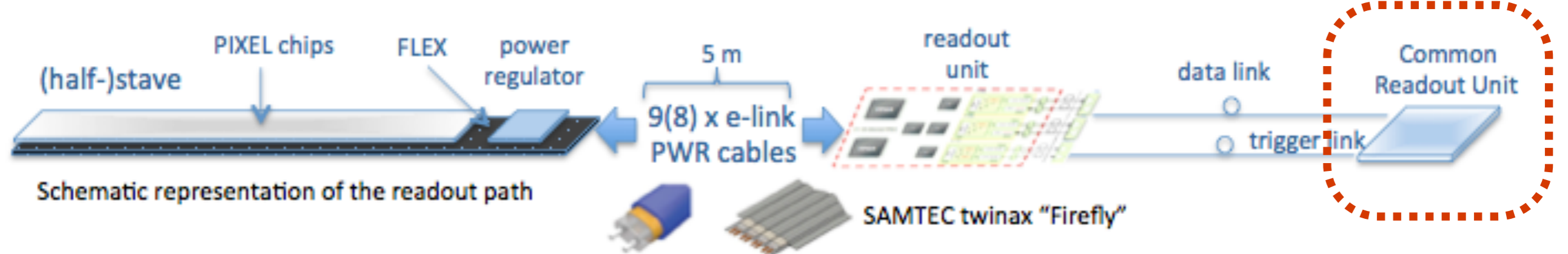
sPHENIX MAPS Geometry II



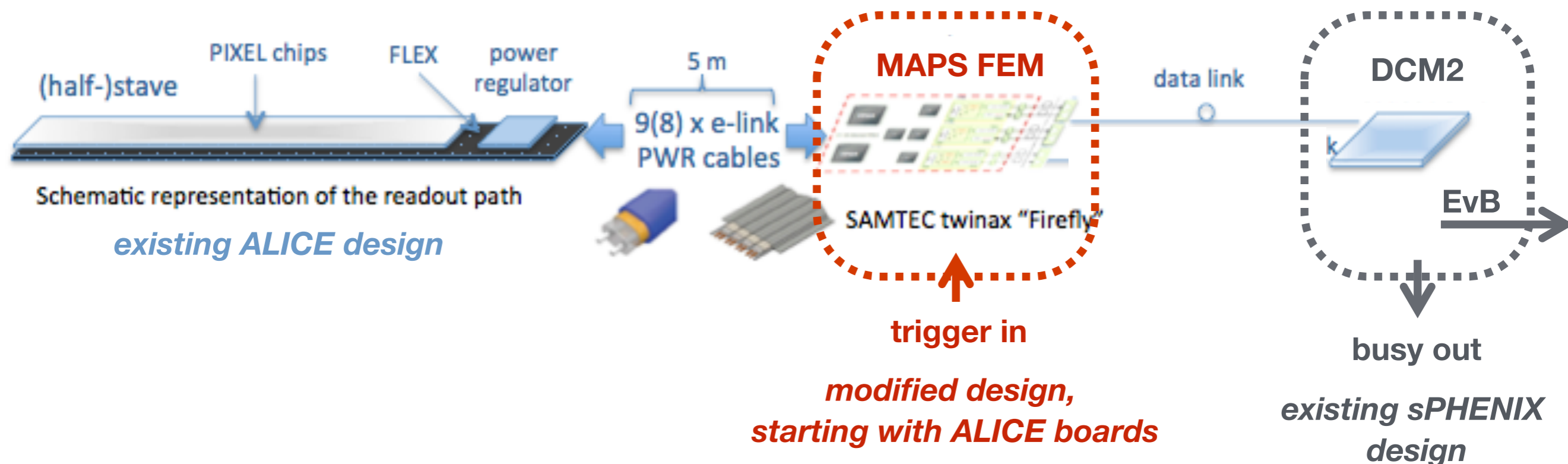
inner clearance to pipe: 1.0 mm
outer clearance to TPC: > 6 cm
* w/o intermediate tracker

MAPS Electronics

ALICE readout path



Plan B: sPHENIX readout path (held as contingency)



Design Drivers

Why not change the stave design to do X?

The ALICE design is well-suited for our physics and exceed our coverage needs. Potential cost savings by shortening the stave are countered by redesign costs and delays. Cooling tube design requires duplicating ALICE water cooling system

Why are three layers needed for sPHENIX?

Additional anchoring points are helpful for: secondary vertexing, pattern recognition, pileup rejection, self-alignment. Reduces need for additional tracking between MAPS and TPC. Studies of fewer layer options are still on-going.

Project Status

Funded!

Purpose: Obtain key R&D support

Funding Profile:

**\$5M spread over 3 years
starting in Oct 2016**

Funding Breakdown:

~1/3 M&S

~1/3 Experiment Staffing

~1/3 Theory Staffing

**Proposals judged on many factors,
coverage from multiple divisions,
strong Theory is necessary to success**

M&S total: \$1.3M Engineering: \$0.5M

Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX

Project #20170073DR

Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX

PI: Liu, Ming, X.; P-25; mliu@lanl.gov

Introduction

A few microseconds after the Big Bang, while still at a temperature of several trillion degrees, the entire universe was permeated with quark-gluon plasma (QGP). Measurements at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), where LANL plays a major role, and the Large Hadron Collider (LHC) at CERN have verified the existence of the QGP [1-4]. However, none of the existing experiments have revealed its microscopic structure, thus motivating a new experiment named sPHENIX [5]. We propose to use a combination of experimental, theoretical, and engineering expertise from LANL's P, T, AOT, and CCS Divisions to develop the next generation heavy ion physics program at LANL. We will design a new cutting-edge, low mass, high efficiency pixel-based inner tracking detector (Figure 1) needed for the sPHENIX experiment. This proposed \$75M experiment will usher in a new era of fundamental discoveries in nuclear science and reveal the internal structure of the QGP near the transition temperature to conventional nuclear matter. The proposed Monolithic Active Pixel Sensor (MAPS [6]) inner tracking detector will provide an order of magnitude improvement in spatial resolution over current technologies and produce the first bottom-quark jet (b-jet) tomographic measurements of the QGP at RHIC. The data will shed new light on our understanding of b-jet interactions with the QGP medium and provide critical new information to pinpoint the transport properties of the QGP. B-jet measurements will fulfill one of the three major science pillars of sPHENIX. We will also develop the state-of-the-art theoretical and computational tools necessary to interpret and optimize the planned experimental measurements. Dr. Geesaman, chair of the DOE Nuclear Science Advisory Committee (NSAC) writes "This LDRD project will be exceptionally valuable for LANL, nuclear science and the nation."

Project Goals

When the fundamental constituents of matter, quarks and gluons, traverse the QGP they scatter and lose a large amount of energy before escaping, a phenomenon that is extremely useful for probing properties of the QGP [7]. The interactions of those particles with the plasma can be used to directly infer its microscopic quasiparticle structure. The final state observable is a jet, the collimated spray of particles created by fragmentation of the scattered high-energy quark or gluon. Bottom quarks, which are ~1,000 times heavier than the light quarks, produce unique energy loss signatures due to their large mass ($4.2 \text{ GeV}/c^2$). At momenta comparable to this scale, bottom quarks will preferentially lose energy via collisions with the plasma quasiparticles and not via gluon radiation, as is preferen-



Figure 1: The sPHENIX conceptual design. Our proposed inner tracking subsystem is closest to the beam line.

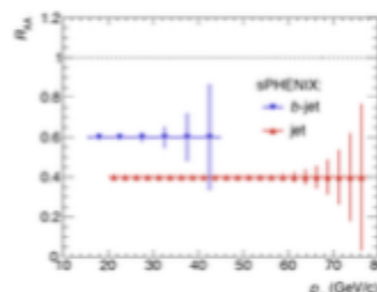


Figure 2: sPHENIX statistical projections for suppression (R_{AA}) illustrating the kinematic coverage for b-jets (blue triangles) and light jets (red triangles) [5].

Liu, Ming X.

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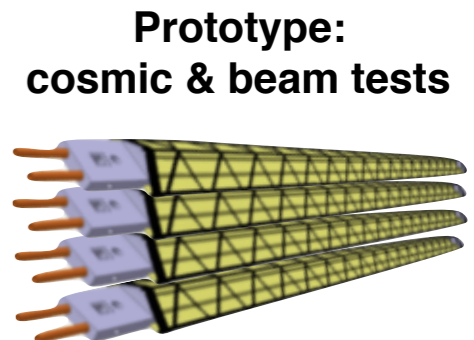
L3 Project Scope

- **Covered by MAPS project**

* *LDRD deliverables*

- MAPS R&D effort

- **4-stave Prototype Tracker with ALICE Readout**
- **sPHENIX readout electronics design & prototyping**
- **Initial Mechanics design** & prototyping & final design
- Servicing design (safety, cooling, power, etc)



- Construction deliverables

- 68 staves assemblies for 3-layer IB (CERN/sPHENIX)
- Mechanical assembly fabrication (LBNL)
- Front end electronics fabrication (x68) (LANL)
- Half-Barrel assembly, metrology (BNL)

- Installation and Commissioning at 1008

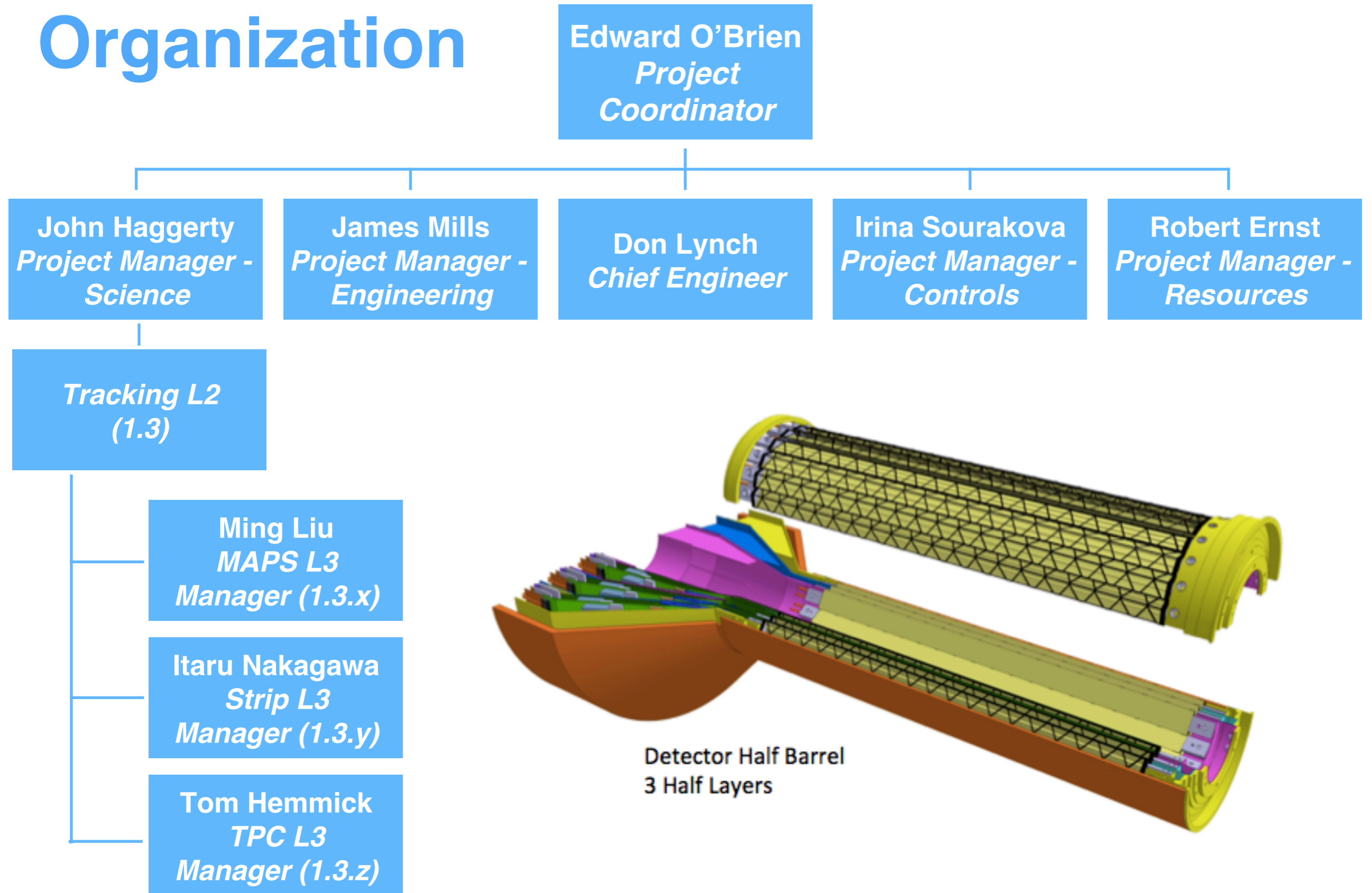
Schedule Drivers

- **sPHENIX Readout Research and Development**
 - Modified readout will begin with ALICE design
 - Multiple prototyping rounds possible
 - Full system test needed before production
- **ALICE ITS Inner Barrel Production**
 - Mid-2017: Arrival of 4-staves for R&D development
 - Mid-2018: Natural end of ALICE production
 - Late-2018: CD-3 begins

Resource/Cost Drivers

- **Building a stave assembly lab from scratch is costly and time consuming (+\$1-2M cost, +1 project years)**
 - Secure access to CERN facility via MOU to extend the assembly line in Switzerland
- **Big project with many deliverables, limited LANL manpower**
 - Bring in large outside institutions
 - LBNL for Mechanics, MIT for Stave assembly
 - Focus LANL on readout speciality
 - Bring in small outside institutions to provide add. manpower

Organization



Budget Overview

ID	WBS	Task Name	Duration	Start	Finish	Cost Center	Fixed Cost	Cost	Activi	Cost per Unit	16	2017				2018				2019														
											Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4										
1	1	MAPS Inner Barrel	1217 days	Mon 10/3/16	Tue 6/1/21		\$0.00	\$5,305,297.33		\$0.00																								
2	1.1	MAPS Inner Barrel Starts	0 days	Sat 10/1/16	Sat 10/1/16		\$0.00	\$0.00		\$0.00	◆ 10/1																							
3	1.2	MAPS Inner Barrel Ends	0 days	Tue 6/1/21	Tue 6/1/21		\$0.00	\$0.00		\$0.00																								
4	1.3	Milestones & Key Tasks	0 days	Mon 10/3/16	Mon 10/3/16		\$0.00	\$6,400.00		\$0.00	▲ 10/3																							
5	1.3.1	ALICE ITS Key Tasks	0 days	Mon 1/2/17	Mon 1/2/17		\$0.00	\$0.00		\$0.00	▲ 1/2																							
6	1.3.1.1	ALICE MAPS Production (7/17)	240 days?	Mon 8/1/16	Fri 6/30/17		\$0.00	\$0.00		\$0.00	■																							
7	1.3.1.2	ALICE ITS IB FPC Production (9/17)	90 days	Mon 5/1/17	Fri 9/1/17		\$0.00	\$0.00		\$0.00	■																							
8	1.3.1.3	ALICE ITS IB Stave Production (1/18)	1 day?	Tue 1/2/18	Tue 1/2/18		\$0.00	\$0.00		\$0.00	■																							
9	1.3.1.4	ALICE ITS IB Stave Assembly (3/18)	262 days	Mon 1/2/17	Tue 1/2/18		\$0.00	\$0.00	ITS c	\$0.00	■ ITS construction																							
10	1.3.1.5	ALICE ITS Electronics Pre-Production (7/17)	100 days	Wed 2/22/17	Tue 7/11/17		\$0.00	\$0.00	ITS Elect	\$0.00	■ ITS Electronics Pre-Production																							
11	1.3.1.6	ALICE ITS Electronics Production (6/18)	240 days	Thu 7/13/17	Wed 6/13/18		\$0.00	\$0.00	ITS E	\$0.00	■ ITS Electronics Production																							
12	1.3.2	sPHENIX Milestones	1195 days	Tue 11/1/16	Tue 6/1/21		\$0.00	\$0.00		\$0.00	■																							
13	1.3.2.1	sPHENIX Technical Design CD-0	0 days	Tue 11/1/16	Tue 11/1/16		\$0.00	\$0.00	CD-0	\$0.00	◆ CD-0 (11/2016)																							
14	1.3.2.2	sPHENIX Technical Design (CD-1/CD-3a)	0 days	Wed 11/1/17	Wed 11/1/17		\$0.00	\$0.00	CD-1	\$0.00	◆ CD-1 (11/2017)																							
15	1.3.2.3	sPHENIX Technical Dewsgin (CD-2)	0 days	Mon 7/2/18	Mon 7/2/18		\$0.00	\$0.00	CD-2	\$0.00	◆ CD-2 (7/2018)																							
16	1.3.2.4	sPHENIX Start Construction (CD-3b)	0 days	Wed 8/1/18	Wed 8/1/18		\$0.00	\$0.00	CD-3	\$0.00	◆ CD-3b (8/2018)																							
17	1.3.2.5	sPHENIX Installed and Ready for Beam	0 days	Tue 6/1/21	Tue 6/1/21		\$0.00	\$0.00	ready	\$0.00																								
18	1.3.3	LDRD Milestones & Critical Tasks	781 days	Mon 10/3/16	Mon 9/30/19		\$0.00	\$6,400.00		\$0.00	■																							
19	1.3.3.1	LDRD Start and End	781 days	Mon 10/3/16	Mon 9/30/19		\$0.00	\$0.00		\$0.00	■																							
20	1.3.3.2	MOU btw LANL and ALICE for R&D	40 days	Mon 10/3/16	Fri 11/25/16	LDRD	\$0.00	\$6,400.00		\$0.00	■ LDRD Physicist[10%]																							
21	1.3.3.3	Setup ALICE Readout Test Stands	0 days	Fri 2/10/17	Fri 2/10/17		\$0.00	\$0.00		\$0.00	◆ 2/10																							
22	1.3.3.4	Complete final sPHENIX Readout Design Review	0 days	Wed 7/26/17	Wed 7/26/17		\$0.00	\$0.00		\$0.00	◆ 7/26																							
23	1.3.3.5	Complete Final MAPS Detector Design (CD-1)	0 days	Thu 11/16/17	Thu 11/16/17		\$0.00	\$0.00		\$0.00	◆ 11/16																							
24	1.3.3.6	sPHENIX Test Beam	21 days	Fri 2/1/19	Fri 3/1/19	LDRD	\$0.00	\$0.00		\$0.00	■																							
25	1.3.3.7	MAPS Final Design (CD-2/CD-3)?	0 days	Mon 10/3/16	Mon 10/3/16		\$0.00	\$0.00		\$0.00	◆ 10/3																							
26	1.4	LANL LDRD	781 days	Mon 10/3/16	Mon 9/30/19	LDRD	\$0.00	\$1,372,560.00	LANL	\$0.00	■																							
111	1.5	sPHENIX Project	1217 days?	Mon 10/3/16	Tue 6/1/21		\$0.00	\$3,926,337.33		\$0.00	■																							
112	1.5.1	sPHENIX Project Management	1217 days	Mon 10/3/16	Tue 6/1/21		\$0.00	\$671,784.00	sPHE	\$0.00	■																							
116	1.5.2	sPHENIX Mechanics Integration	289 days	Thu 11/2/17	Tue 12/11/18		\$0.00	\$307,000.00		\$0.00	■																							
117	1.5.2.1	Stave Support Frame & Global Interface to sPHENIX	115 days	Thu 11/2/17	Wed 4/11/18		\$0.00	\$158,600.00		\$0.00	■																							
122	1.5.2.2	Cooling System	25 days	Wed 8/1/18	Tue 9/4/18		\$0.00	\$51,000.00		\$0.00	■																							
126	1.5.2.3	Safety Systems	70 days	Wed 9/5/18	Tue 12/11/18		\$0.00	\$56,000.00		\$0.00	■																							
130	1.5.2.4	Stave Assembly Tooling	45 days	Thu 4/12/18	Wed 6/13/18		\$0.00	\$41,400.00		\$0.00	■																							
134	1.5.3	Mechanics Final Design Review	12 days	Thu 6/14/18	Fri 6/29/18		\$0.00	\$11,000.00		\$0.00	■																							
138	1.5.4	MAPS Inner Barrel Review (CD-2/CD-3)	12 days	Mon 7/2/18	Tue 7/17/18		\$0.00	\$28,000.00		\$0.00	■																							
142	1.5.5	Productions	534 days?	Thu 6/14/18	Tue 6/30/20		\$0.00	\$2,660,153.33	Prod	\$0.00	■																							
143	1.5.5.1	Full Pre-Production-Mechanical System Mock Up Test	90 days	Thu 6/14/18	Wed 10/17/18		\$0.00	\$52,800.00		\$0.00	■ Mechanical Engineer[13%]																							
144	1.5.5.2	Procurements	180 days?	Wed 8/1/18	Tue 4/9/19		\$0.00	\$2,246,020.00		\$0.00	■																							
162	1.5.5.3	Assembly and Testing at BNL	400 days	Wed 12/19/18	Tue 6/30/20		\$0.00	\$361,333.33		\$0.00	■																							
171	1.5.6	Installation	131 days	Wed 7/1/20	Wed 12/30/20		\$0.00	\$248,400.00		\$0.00	■																							
176	1.5.7	Ready for beam	0 days	Wed 12/30/20	Wed 12/30/20		\$0.00	\$0.00		\$0.00	■																							

Timeline of Major Tasks

- **Key Dates**

- Start of LDRD funding: October 1 2016
- Arrival of 4-staves: mid 2017
- Full System Readout Test: late 2017
- Readout Electronics Design Finalization: early 2018
- **End of ALICE ITS Inner Stave assembly: mid 2018 (latest ITS update)**
- Test Beam Operation: early 2019
- Ready for CD-2 by July 2018
- **Ready for CD-3 by August 2018 (sPHENIX CD-3b date)**
- Inner Barrel Stave Construction (9 mo): late 2018 to mid 2019

Issues and Concerns

(1) Mating the ALICE and sPHENIX production schedules

Problem: now only $\sim 1/4$ year gap between ITS and CD-3

Strategy: train experts in-situ, maintain production line at low effort, & ramp back up, look for opportunities to close the gap

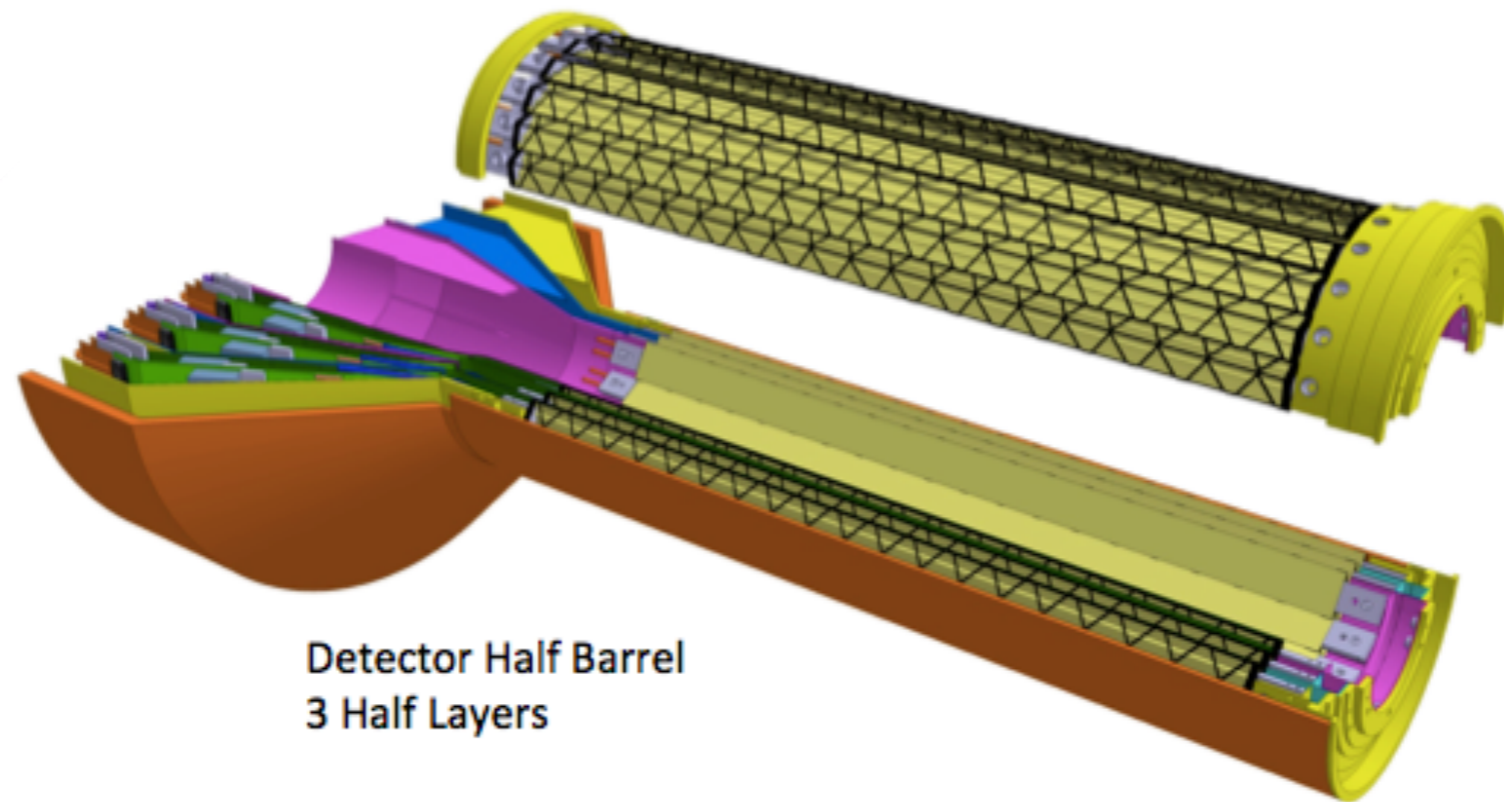
(2) Long Development Time for Readout Electronics

Problem: Full custom board design may be required

Strategy: Early review of options, early start on design work

Plan-B: Proof-of-principle readout with one stave for technical review

Summary



MAPS is a conservative approach to a tough problem

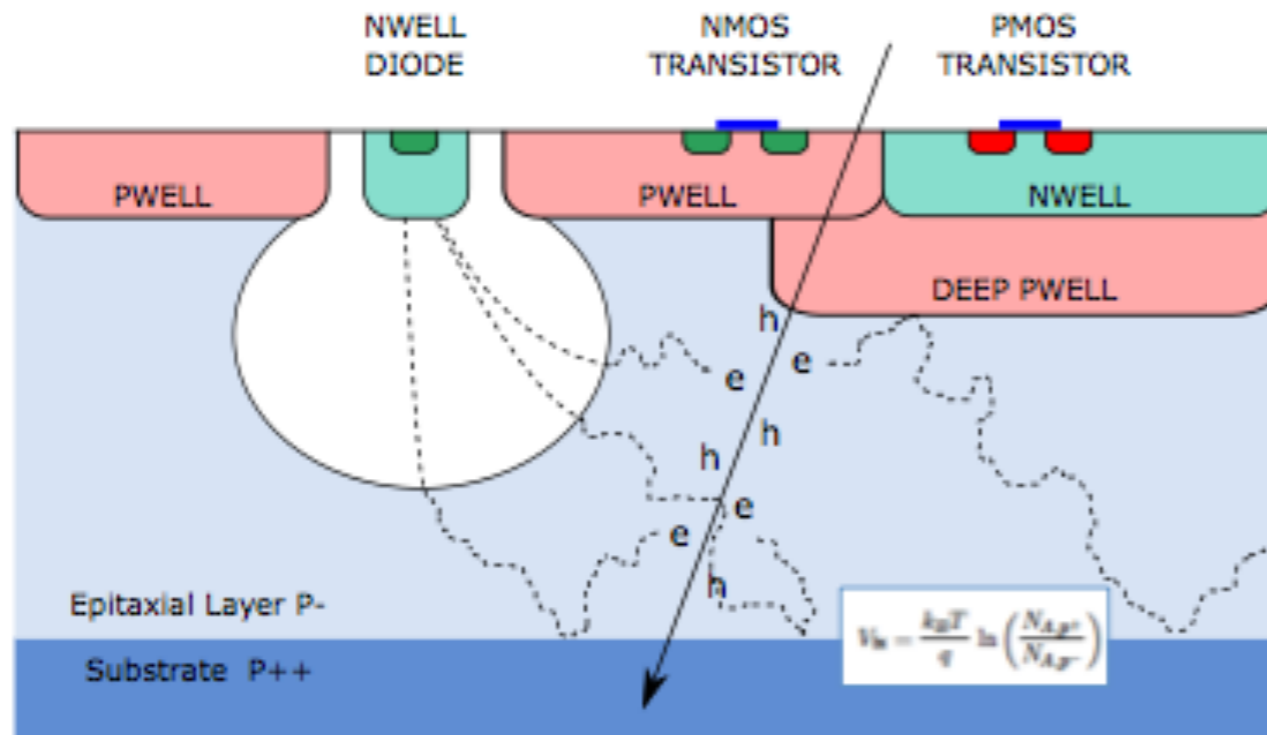
Retiring the Readout risk is a top priority

Work closely with ALICE to keep the project schedules coupled

Backups

ALPIDE Pixel Technology

CMOS Pixel Sensor using TowerJazz 0.18μm CMOS Imaging Process



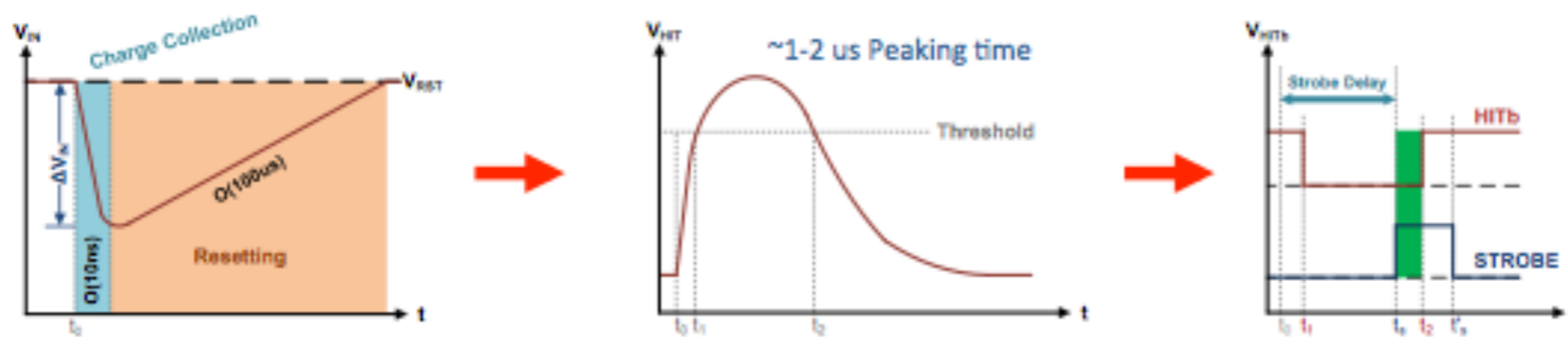
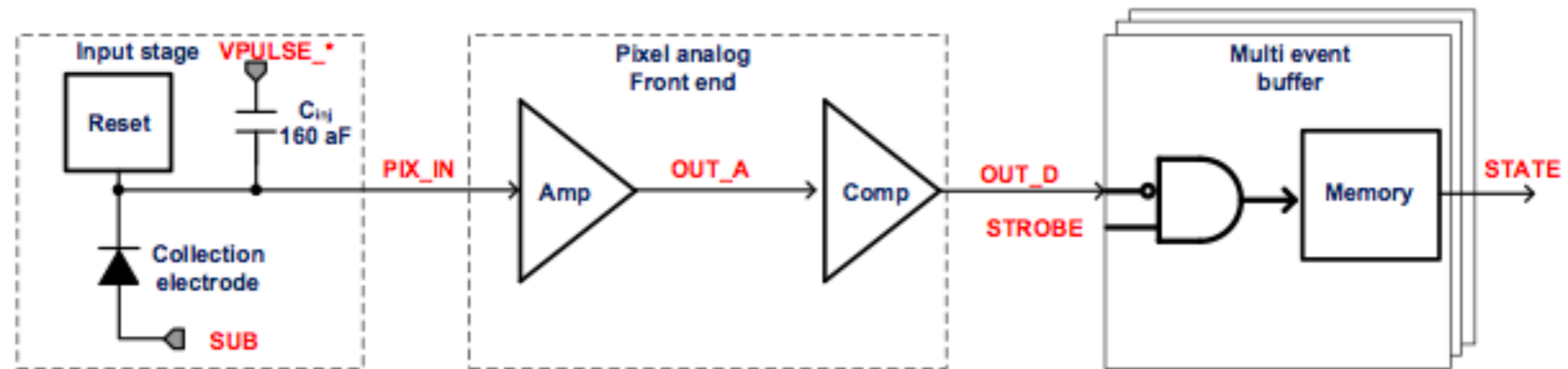
Tower Jazz 0.18 μm CMOS

- feature size 180 nm
- metal layers 6
- gate oxide 3nm

substrate: $N_A \sim 10^{18}$
epitaxial layer: $N_A \sim 10^{13}$
deep p-well: $N_A \sim 10^{16}$

- ▶ High-resistivity ($> 1\text{k}\Omega\text{ cm}$) p-type epitaxial layer (18μm to 30μm) on p-type substrate
- ▶ Small n-well diode (2 μm diameter), ~100 times smaller than pixel => low capacitance
- ▶ Application of (moderate) reverse bias voltage to substrate (contact from the top) can be used to increase depletion zone around NWELL collection diode
- ▶ Deep PWELL shields NWELL of PMOS transistors to allow for full CMOS circuitry within active area

ALPIDE Operation

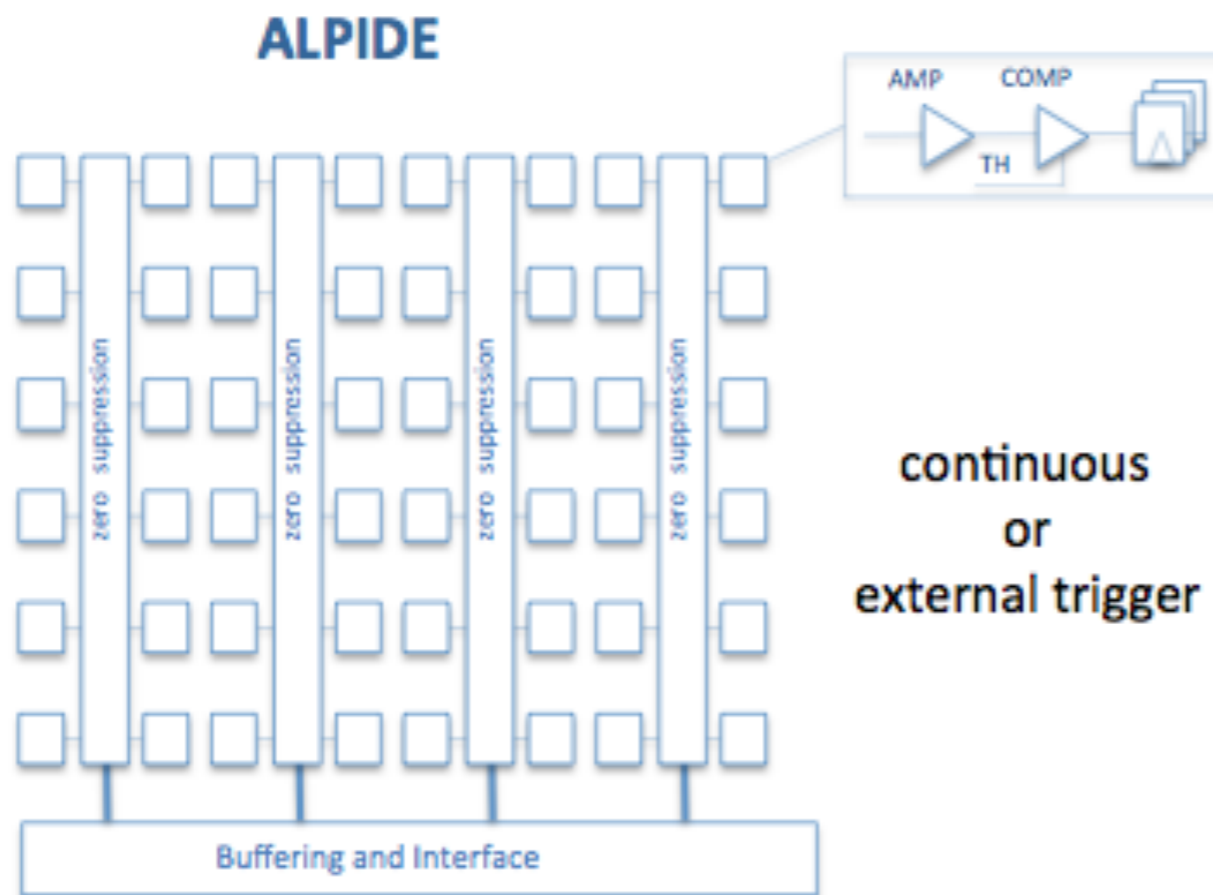


ultra low-power front-end circuit
40nW / pixel

Front-end acts as delay line

- Sensor and front-end continuously active
- Upon particle hit front-end forms a pulse with $\sim 1\text{-}2\mu\text{s}$ peaking time
- Threshold is applied to form binary pulse
- Hit is latched into a (3-bit) memory if strobe is applied during binary pulse

ALPIDE Readout



Architecture

- ▶ In-pixel amplification
- ▶ In-pixel discrimination
- ▶ In-pixel (multi-) hit buffer
- ▶ In-matrix sparsification

Key Features

- ⊙ 28 μm x 28 mm pixel pitch
- ⊙ Continuously active, ultra-low power front-end (40nW/pixel)
- ⊙ No clock propagation to the matrix → ultra-low power matrix readout (2mW whole chip)
- ⊙ Global shutter (<10 μs): triggered acquisition or continuous